MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2019/2020

EMF4066 – RF CIRCUIT DESIGN
(TE)

9 MARCH 2020
9:00 A.M. – 11:00 A.M.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 9 pages with 4 Questions only.
2. Attempt **ALL FOUR** questions.
3. Please print all your answers in the Answer Booklet provided.

Question 1

(a) A cascaded attenuator shown in Figure Q1(a) is used to reduce the source voltage to load R_L. It is required that the image impedance looking into the input of the attenuator be equal to the load resistor, such as $Z_i = R_L$.

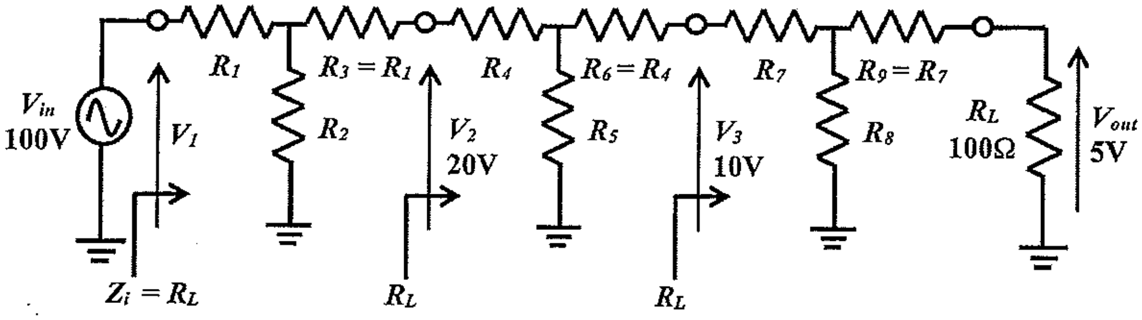

Figure Q1(a)

(i) State ONE (1) usage of attenuator in a typical RF application.

[1 mark]

(ii) Name the type of attenuator used in the above circuit.

[1 mark]

(iii) For each stage, determine the attenuation factor (in dB). What is the total attenuation factor (in dB) for this cascaded system?

[4 marks]

(iv) Calculate the values of R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8 and R_9.

[9 marks]

(b) Figure Q1(b) shows a quarter-wave matching transformer with characteristic impedance, Z_l = 54.8 Ω is used to match a load, Z_L to a 75 Ω lossless transmission line.

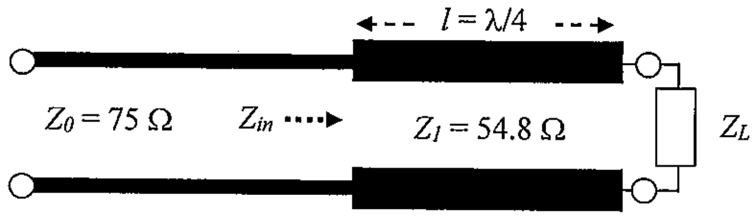

Figure Q1(b)

(i) State TWO (2) advantages and TWO (2) disadvantages of using quarter-wave matching transformer in impedance matching, compared to conventional lumped element matching.

[4 marks]

Continued ....

(ii) Show that the characteristic impedance of the quarter-wave transformer

$$Z_1 = \sqrt{Z_0 \times Z_L}$$

where Z_0 is the characteristic impedance of the lossless transmission line.

[4 marks]

(iii) Determine Z_L.

[2 marks]

Question 2

(a) State FOUR (4) advantages and FOUR (4) disadvantages of microstrip lines in planar printed circuit board (PCB) implementations.

[8 marks]

(b) Design a microstrip transmission line for a 100 Ω characteristic impedance. The substrate thickness (d) is 0.158 cm, with relative dielectric constant ε_r = 2.2. What is the guide wavelength on this transmission line if the frequency is 4 GHz?

***(Hints** – Use the microstrip equations listed in Appendix and assume $W/d < 2$)*

[8 marks]

(c) A microwave transistor amplifier has the following S-parameters (Z_o= 50 Ω) measured at 5 GHz.

$S_{11} = 0.641\angle{-171.3°} = -0.634 - j0.097$,
$S_{21} = 2.058\angle{28.5°} = 1.809 + j0.982$,
$S_{12} = 0.057\angle{16.3°}$, $= 0.0547 + j0.0160$ and
$S_{22} = 0.572\angle{-95.7°} = -0.0568 - j0.569$.

(i) Define the terms *unconditional stability* and *conditional stability* for a transistor amplifier.

[4 marks]

(ii) Calculate the Rollette stability factor k and Δ, and state the stability condition.

[5 marks]

Continued ....

Question 3

(a) A filter has the S_{21} (in dB) shown in Figure Q3. It is measured from approximately 40 MHz to 1200 MHz, with a 50 Ω reference impedance (Z_0).

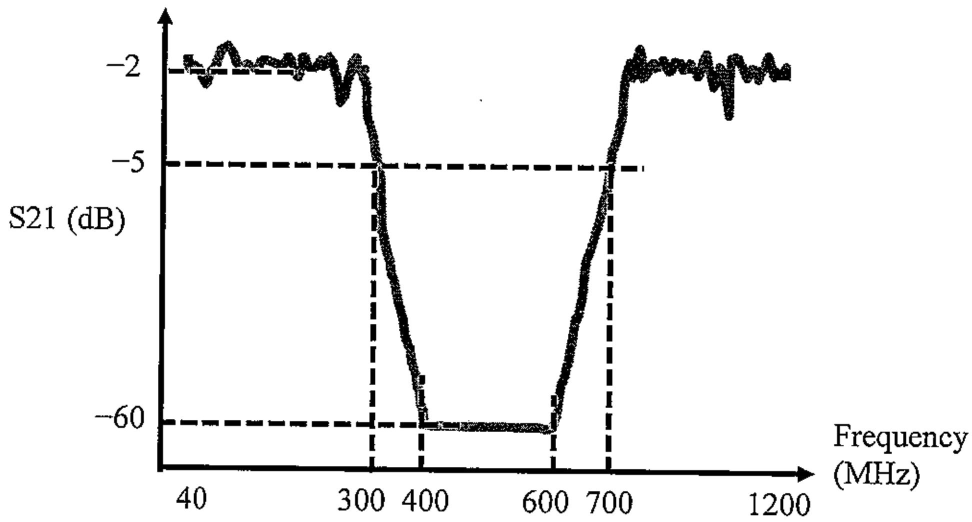

Figure Q3

(i) What type of filter is shown in the above measurement?

[1 mark]

(ii) Determine the insertion loss, cut-off frequencies, center frequency and 3 dB bandwidth of the filter.

[5 marks]

(iii) What are the pass-band frequencies, stop-band frequencies and rejections of the filter?

[6 marks]

(b) Design a stepped-impedance low-pass filter having a maximally flat (Butterworth) response and a cutoff frequency of 2.5 GHz. It is necessary to have more than 20 dB attenuation at 3.75 GHz. The filter impedance is 50 Ω, the highest practical impedance is 120 Ω and the lowest is 20 Ω. Consider the filter is implemented with a microstrip FR-4 substrate (thickness, d = 0.158 cm and relative dielectric constant, ε_r = 4.2). Calculate all the required electrical lengths (βl_i) along with the physical microstrip line widths (W_i) and lengths (l_i).

***(Hints** – Use the microstrip equations, Figure 1 and Table 2 in the Appendix)*

[13 marks]

Continued ....

Question 4

(a) Draw THREE (3) resistive negative feedback topologies each for both the Bipolar Junction Transistor (BJT) and Field Effect Transistor (FET) broadband amplifier.

[6 marks]

(b) A two-stage power amplifier consisting of first stage pre-amplifier and second stage power amplifier for linear operation at 4 GHz, are to be designed. The input signal power is 0 dBm. The input and output power relationships for amplifiers **Amp_A** and **Amp_B** at 4 GHz, are shown in **Figure Q4(b)**. One will be used as pre-amplifier while the other will be the power amplifier.

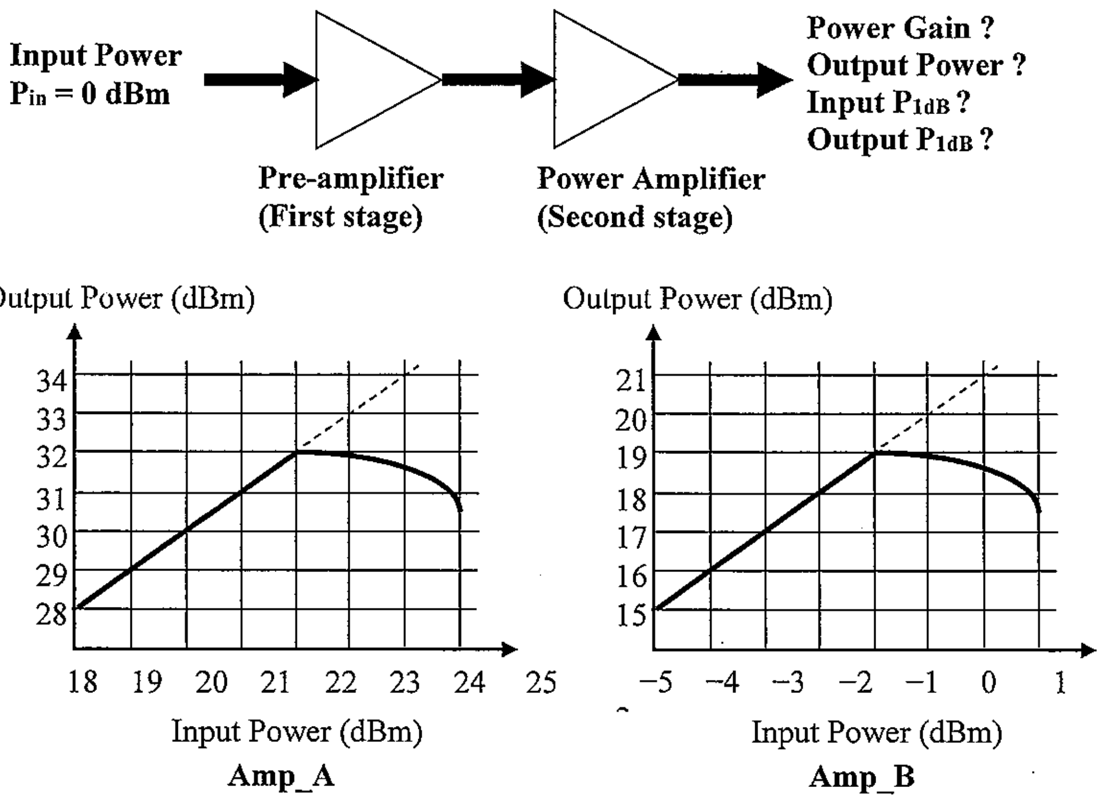

Figure Q4(b)

(i) Explain briefly the function and usage of pre-amplifier used in this design.

[3 marks]

(ii) Determine the linear power gain, 1 dB gain compression, input and output power at 1 dB gain compression for **Amp_A**.

[4 marks]

Continued …….

(iii) Determine the linear power gain, 1 dB gain compression, input and output power at 1 dB gain compression for **Amp_B**.

[4 marks]

(iv) Which amplifier is suitable for the first stage? Explain your answer.

[2 marks]

(v) Which amplifier is suitable for the second stage? Explain your answer.

[2 marks]

(vi) Calculate the power gain and output power obtained after the first stage.

[2 marks]

(vii) Calculate the power gain and output power obtained from this design.

[2 marks]

Continued ....

Appendix – Useful Formulas

Microstrip equations for dielectric constant and characteristic impedance

- The effective dielectric constant of a microstrip line is given by:

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \frac{1}{\sqrt{1 + 12d/W}}$$

- Given the dimensions of microstrip line, characteristic impedance can be calculated as:

$$Z_0 = \begin{cases} \dfrac{60}{\sqrt{\varepsilon_e}} \ln\left(\dfrac{8d}{W} + \dfrac{W}{4d}\right) & for \quad W/d \le 1 \\ \dfrac{120\pi}{\sqrt{\varepsilon_e}\left[\dfrac{W}{d} + 1.393 + 0.667\ln(\dfrac{W}{d} + 1.444)\right]} & for \quad W/d \ge 1 \end{cases}$$

- For a given characteristic impedance and dielectric constant, the W/d ratio can be found as:

$$\frac{W}{d} = \begin{cases} \dfrac{8e^{A}}{e^{2A} - 2} & for \quad W/d < 2 \\ \dfrac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \dfrac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(B - 1) + 0.39 - \dfrac{0.61}{\varepsilon_r}\right\}\right] & for \quad W/d > 2 \end{cases}$$

where

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

Continued ....

Given:

Input and Output reflection coefficient

$$\Gamma_1 = \Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \qquad \Gamma_2 = \Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S}$$

Power Gain, Available Gain and Transducer Gain

$$G_p = \frac{|S_{21}|^2\left(1 - |\Gamma_L|^2\right)}{\left(1 - |\Gamma_{in}|^2\right)|1 - S_{22}\Gamma_L|^2} \qquad G_A = \frac{|S_{21}|^2\left(1 - |\Gamma_S|^2\right)}{\left(1 - |\Gamma_{out}|^2\right)|1 - S_{11}\Gamma_S|^2}$$

$$G_T = \frac{|S_{21}|^2\left(1 - |\Gamma_S|^2\right)\left(1 - |\Gamma_L|^2\right)}{\left|\left(1 - \Gamma_S\Gamma_{in}\right)\right|^2|1 - S_{22}\Gamma_L|^2}$$

Rollett factor

$$k = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}||S_{21}|} \quad \text{and} \quad \Delta = S_{11}S_{22} - S_{12}S_{21}$$

Output and Input stability circles parameters center and radius

$$r_{out} = \frac{|S_{12}S_{21}|}{\left||S_{22}|^2 - |\Delta|^2\right|} \qquad C_{out} = \frac{\left(S_{22} - S_{11}^*\Delta\right)^*}{|S_{22}|^2 - |\Delta|^2}$$

$$r_{in} = \frac{|S_{12}\,S_{21}|}{\left||S_{11}|^2 - |\Delta|^2\right|} \qquad C_{in} = \frac{\left(S_{11} - S_{22}^*\Delta\right)^*}{|S_{11}|^2 - |\Delta|^2}$$

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Figure 1 – Attenuation versus normalized frequency for Butterworth prototypes

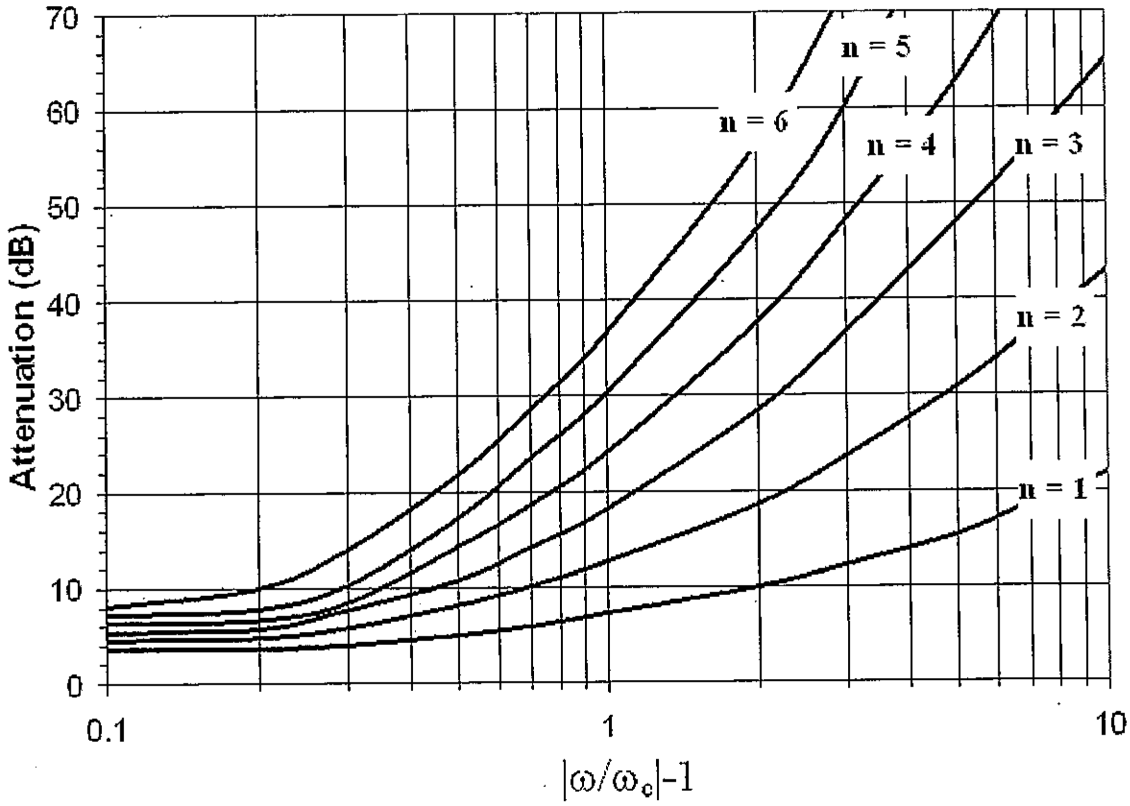

Table 2 – Element values for Butterworth Low-Pass Filter Prototype

N	g1	g2	g3	g4	g5	g6	g7
1	2.000	1.000					
2	1.414	1.414	1.000				
3	1.000	2.000	1.000	1.000			
4	0.765	1.848	1.848	0.765	1.000		
5	0.618	1.618	2.000	1.618	0.618	1.000	
6	0.517	1.414	1.932	1.932	1.414	0.517	1.000

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